

The University of Chicago

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A SMALL DEPOSIT IN THE
TEXAS PERMIAN

A PART OF A DISSERTATION SUBMITTED TO
THE FACULTY OF THE DIVISION OF THE
PHYSICAL SCIENCES IN CANDIDACY FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY AND PALEONTOLOGY

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ENVIRONMENTAL SIGNIFICANCE OF A SMALL DEPOSIT IN THE TEXAS PERMIAN¹

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ABSTRACT

The Permian redbeds of north-central Texas have long been recognized as the sediments of a shoreline of aggradation, but little progress has thus far been made in explaining the specific circumstances of origin of distinctive individual deposits. The study which follows is an attempt to achieve this aim in the case of a single small deposit which represents a type of special interest to the paleontologist, since it contains a diversified assemblage of mixed terrestrial and marine fossils. This deposit is interpreted as a partly re-worked channel-fill laid down by a temporary fluvial distributary discharging across extended tidal flats into a shallow coastal lagoon.

INTRODUCTION

LOCATION

The deposit described in this study—hereinafter referred to as “the fossiliferous deposit”—is exposed along a fork of Mitchell Creek in the northeast portion of Baylor County, Texas (see Fig. 1). It may be reached on foot from a point on U.S. Highway 283 three miles north of the intersection at Mabelle. About one-half mile east of the highway the upland surface terminates abruptly in a ragged escarpment overlooking the creek valley. One fork of the creek here flows through a steep-sided draw between the escarpment and an outlying mesa. This draw will be referred to as “Mabelle Draw,” and the locality as the “Mabelle Draw locality.”

LOCAL STRATIGRAPHIC RELATIONSHIPS

The shape and disposition of the fossiliferous deposit in the horizontal plane are largely concealed by overlying sediments; but in cross section, as exposed along the stream course, it appears as a

thin lens of gray-to-yellowish clay, silt, sand, and gravel—irregularly laminated, poorly sorted, unconsolidated, and, for the most part, without visible bedding. It has a maximum exposed thickness of about 10 or 12 feet and is approximately 1,000 feet wide in the north-south direction.

The fossiliferous deposit is overlain, and bordered, by a sheet of gray or reddish-gray sediment consisting of well-sorted layers of silt and sand commonly arranged in an imbricate structure. Many of the sandy layers are more or less indurated and stand out as ledges in the exposures. This deposit will henceforth be designated the “imbricated deposit.” It extends at least 300 feet beyond the fossiliferous deposit to both the north and the south and has a maximum observed thickness of about 5 feet.

The fossiliferous deposit and the imbricated deposit together form an extensive seam of relatively coarse and drab-colored sediment, which is sandwiched in between thick strata of fine reddish and purplish mudstone. Mudstone deposits crop out over a vast area in north-central Texas and attain a combined thickness of many hundreds of feet. For the purposes of this study “the

¹ Submitted, in more expanded form, in September, 1942, to the faculty of the Division of Physical Sciences at the University of Chicago in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

mudstone" may be considered as a sort of undifferentiated "background" deposit of indefinite horizontal and vertical extent.

There are two limestone layers which

40 feet above the top of the imbricated deposit.

AGE RELATIONSHIPS

The geologic age of the fossiliferous deposit may be determined from its strati-

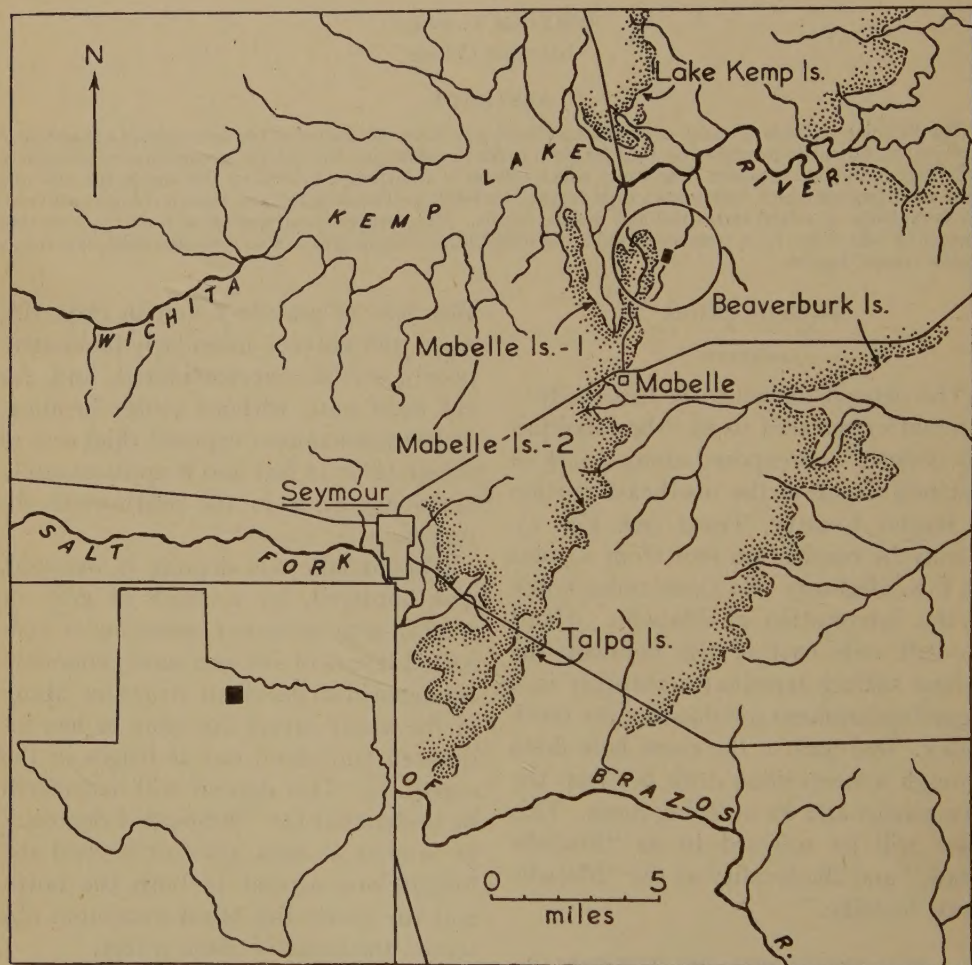


FIG. 1.—Index map of Baylor County, showing location of Mabelle Draw. The area covered by the geologic map (Fig. 2) is indicated by the black rectangle in the circle. Inset shows location of Baylor County in Texas.

enter into the picture at Mabelle Draw. The lower layer generally forms the rim of the draw, and the upper one, a terrace a short distance back from the rim. The two layers are each about $1-1\frac{1}{2}$ feet thick and are separated by 6 or 7 feet of mudstone. The lower layer is about

graphic position in reference to the two limestone layers.

One of these layers is shown by M. M. Garrett, A. M. Lloyd, and G. E. Laskey²

² "Geologic Map of Baylor County, Texas" (Austin: University of Texas, Bureau of Economic Geology, 1930). Scale: 1/48,000.

on their "Geologic Map of Baylor County." They show only one layer in the vicinity of Mabelle Draw and identify this as the first, or uppermost, division of the "Maybelle" limestone.

The name "Maybelle" was originally given by A. S. Romer in 1928 to "a scarp-forming limestone . . . which crosses central Baylor County from the Big Wichita River near the Kemp Lake dam to the Salt Fork about ten miles below Seymour."³

In the first edition of their Baylor County map, which appeared in 1930, Garrett, Lloyd, and Laskey plotted the outcrops of a number of layers of limestone between the Kemp Lake dam and the Salt Fork. Five they grouped together as divisions of the "Maybelle" limestone; and a sixth, about 40 feet above the Maybelle series, they named the "Lake Kemp limestone." In their columnar section they showed all of these limestone layers as members of a formation which they called the "Lueders formation."⁴

E. H. Sellards, in 1932, when he undertook to divide the entire lower Permian of north-central Texas into separate formations, followed Garrett, Lloyd, and Laskey in selecting the top of the Lake Kemp limestone as the upper limit of his Lueders formation, and the top of the Talpa limestone, 30 feet below the Maybelle series, as its base.⁵

Under the terms of this definition, the only question in regard to the age of the fossiliferous deposit at Mabelle Draw is

whether it is located stratigraphically above the Talpa and belongs to the Lueders formation or whether it is below the Talpa and belongs to the underlying formation, which is the Clyde. Unfortunately, the Talpa limestone does not extend as far north as Mabelle Draw (see Fig. 1); so there is no horizon-marker in this locality to separate the bottom of the Lueders formation from the top of the Clyde. The position of the fossiliferous deposit with reference to the boundary between these two formations can be determined only by comparison of the stratigraphic interval between the limestone layers and the fossiliferous deposit at Mabelle Draw with the stratigraphic interval between the uppermost member of the Maybelle limestone and the established base of the Lueders formation farther south. The fossiliferous deposit is 50 feet below the upper limestone at Mabelle Draw. The base of the Lueders formation farther south, according to Garrett, Lloyd, and Laskey, is fully 75 feet below the uppermost member of the Maybelle. Assuming no marked lateral variations in thickness, the fossiliferous deposit would therefore be about 25 feet above the base of the Lueders and should be assigned to that formation.

It is possible, of course, that the limestone mapped by Garrett, Lloyd, and Laskey in the vicinity of Mabelle Draw as the uppermost member of the Maybelle may have been the lower, rather than the upper, of the two limestones there present. If so, the inferred interval between the fossiliferous deposit and the uppermost member of the "Maybelle" would be shorter, by 7 feet, and its distance above the base of the Lueders formation correspondingly greater.

Sellard's classification of the Lower Permian, including the Lueders formation, has not been accepted without

³ "Vertebrate Faunal Horizons in the Texas Permo-Carboniferous Red Beds," *Univ. Tex. Bull.* 2801 (1928), p. 74.

⁴ Garrett, Lloyd, and Laskey, *op. cit.*

⁵ E. H. Sellards, W. S. Adkins, and F. B. Plummer, "The Geology of Texas," *Univ. Tex. Bull.* 3232 (1932), p. 169.

criticism. Romer,⁶ in 1935, advocated on faunal grounds that the Lueders formation and the Clyde be transferred from the Wichita group to the Clear Fork. M. G. Cheney,⁷ in 1940, advocated that all the formations in Sellards' Wichita group be raised to the rank of groups and that the limestone members in these formations be raised to the rank of formations. The writer's adherence, in this study, to the original classification proposed by Sellards implies no judgment upon the suggestions of Romer and Cheney; it is simply a matter of acquiescence in the most widely accepted usage.

The writer would like to suggest one minor change in Sellards' classification: namely, the emending of the spelling of the name "Maybelle" to "Mabelle." As previously stated, the "Maybelle" limestone was so named by Romer in 1928. Romer gave no type locality, stating merely that the limestone was "known locally" by that name. The local usage, however, obviously derives from the name of a post office 8 miles east of Seymour, which is spelled "Mabelle" not only on the post office itself but also in the official lists of the Office of the Postmaster General.

DESCRIPTIONS OF ASSOCIATED DEPOSITS

MUDSTONE

The mudstone which surrounds the fossiliferous deposit at Mabelle Draw is typical of the thick series of argillaceous sediments which are comprised within the Wichita and Clear Fork groups of north-central Texas. Although the continuity of this series is interrupted at intervals by limestone layers, which

stratigraphers have utilized as horizon-markers, the great mass of sediment between these layers has remained, for the most part, "undifferentiated."

The 50-foot section of mudstone exposed at Mabelle Draw exhibits little significant sedimentological variation in either the horizontal or the vertical direction. It is undoubtedly true, however, that a more intensive study, conducted over a wider area, would reveal the presence of distinct depositional units.

The mudstone does not look much like stone at the surface. It weathers to a soft, porous clay, which everywhere forms a foot-thick coating over the bedrock. The latter would seem to be subject to disintegration at a very rapid rate, for a piece of it, placed in water, almost immediately crumbles into mud; but in its natural environment it seems to receive considerable protection from the surface clay, which becomes very sticky and nearly impervious when wet.

Owing to the coating of weathered material, it is impossible to observe the color of the fresh mudstone except in very recent natural or artificial excavations. The writer therefore sank test-pits at various points to ascertain whether there was any significant difference in the color of the weathered material as compared with that of the bedrock. The only observed difference was that the weathered material, being more porous, characteristically exhibited a somewhat lighter color-tone.

The actual color of the mudstone may therefore be safely inferred from the color of the surface material. The dominant hue, as indicated by the designation "redbeds," is a rich reddish brown; but the red shades off into vague horizontal bands of lavender, sienna, and gray. The banding seems to be due, for the most

⁶ "Early History of Texas Redbeds Vertebrates," *Bull. Geol. Soc. Amer.*, Vol. XLVI (1935), pp. 1597-1627.

⁷ "Geology of North-Central Texas," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XXIV (1940), pp. 65-118.

part, to variations in the relative abundance of iron and manganese oxides. The color effect is generally the result of a more or less uniform staining by combinations of these oxides, but it may also be concentrated in concretionary crusts and pellets.

One striking exception to the usual color pattern may be noted: Where the mudstone lies in contact with the under side of the fossiliferous deposit, it is generally bleached gray to a depth of 2 or 3 feet. This is presumably due to the reducing effect of the carbonaceous material in the fossiliferous deposit.

A singular feature of the mudstone is its apparent total lack of lamination. Even polished surfaces coated with balsam show no trace of the usual depositional structures displayed by fine-grained sediments. They show, instead, a complex "secondary" structure which resembles that of serpentine and which is obviously due, as in the case of the metamorphic rock, to profound chemical alteration coupled with brecciation resulting from volume changes.

It is conceded, of course, that this condition may have been brought about, in considerable measure, by recent weathering; but the same structure was observed in specimens secured by the writer from his deepest test-pits, and it is therefore thought to be due in part, also, to earlier diagenetic changes.

Slickensiding is abundant everywhere throughout the mudstone and occurs in two forms, which are apparently genetically distinct. There are numerous steeply inclined, but relatively flat, surfaces—commonly more or less coated with manganese oxides—that seem to be the result, chiefly, of settling; and, in addition to these, there are myriads of irregular little cone-shaped surfaces, occurring all through the mudstone, that seem to

have been caused by internal swelling. The slickensides, of course, are all of secondary origin.

Textural analyses of typical samples of the mudstone reveal little more than a consistent limitation in the range of particle size to dimensions that fall within the silt and clay categories.⁸ After dispersion by standard methods⁹ all but a fraction of a per cent of each sample was found to pass readily through a $\frac{1}{16}$ -mm. sieve—and under the microscope, even this insignificant fraction of a per cent proved, in every instance, to be composed mainly of undissociated aggregates.

For the sake of thoroughness the writer executed a number of pipette analyses on mudstone samples; but the results of these analyses are felt to be hardly worth presenting here, as the size-frequency distribution obtained by rudely dissociating an indurated mud after 200 million years of diagenetic alteration can scarcely be expected to correspond very closely to the size-frequency distribution possessed by the mud at the time of its deposition.

As at many other localities in north-central Texas, the mudstone contains, at Mabelle Draw, a remarkable assortment of different kinds of concretions. They seem to be roughly divisible into two main types, which may be called, for the sake of convenience, the "nodule" type and the "seam" type, the former being isolated, potato-like structures, and the latter, more massive, tabular affairs running either slantwise or horizontally through the mudstone.

Seam-type concretions occur most

⁸ See C. K. Wentworth, "A Scale of Grade and Class Terms for Clastic Sediments," *Jour. Geol.*, Vol. XXX (1922), pp. 377-92.

⁹ The methods and apparatus used in making these analyses are described in W. C. Krumbein and F. J. Pettijohn, *Manual of Sedimentary Petrography* (New York: D. Appleton-Century Co., 1938), pp. 48, 53, 56-68, 166-68.

abundantly in the first 8 or 10 feet of mudstone immediately subjacent to the limestone layers and, like the latter, are buff-gray in color. Individual seams are commonly 3 or 4 inches thick and may extend laterally, or lengthwise, for several feet—though seams of this size are seldom unbroken or continuous throughout the whole of their extent. Externally, the seams are generally “swollen” in appearance and crisscrossed with fine creases. They may also be pock-marked with tiny pits—like the pits on the opposing surfaces of a stylolite. Internally, they consist of compact, crypto-crystalline, gray calcite with a generous admixture of clay. Some of the larger specimens contain small “shrinkage” cavities,¹⁰ which are generally half-filled with a residual white powder of clay. The powder not infrequently conceals a few clear crystals of barite. Polished sections reveal the presence of numerous fine cracks connecting the internal cavities with the exterior. No traces of any recognizable growth structure are visible.

Concretions of the nodular variety seem to be distributed in an entirely random manner. Some portions of the mudstone are full of them; elsewhere, not a single specimen can be found. They range in size up to the dimensions of a cantaloupe but are generally less evident than the seam-type concretions, since they are usually of the same color as the surrounding mudstone. A variety of surface textures occur. Some, especially the smaller ones, are smooth; others are covered with a reticulate fencework of thin ridges or with oölitic, or botryoidal, deposits. Internally, these concretions generally exhibit a geode-like structure. They have relatively large internal cavi-

ties, which are angulated and irregular, as if formed by the enlargement of intersecting “shrinkage” cracks like those in the seam-type concretions. The cavities are generally rather heavily crusted over with fine crystals of calcite or dolomite and may contain a few large, wedge-shaped crystals of barite, with perhaps a bundle or two of barite fibers in the middle. The bodies, or shells, consist of coarsely crystalline calcite, dolomite, barite, and siderite and commonly exhibit a certain degree of concentric variation in color, texture, and composition. An occasional specimen may have a shell which is septated by veins of clear crystalline calcite or barite ramifying outward from the interior.

The question of the origin of these concretions and of their bearing, if any, upon the problem of the origin of the fossiliferous deposit is a difficult one and may, for the moment, be held in abeyance. It may be noted at this point, however, that a good deal of the complexity observed among specimens of the nodule type may be due, in part, to very recent diagenetic alterations. The writer has repeatedly noted that nodules which have lain a long time weathering on the surface commonly exhibit a much greater degree of complexity than those which are found *in situ*; that they are more likely to be coated, for instance, with oölitic or botryoidal deposits; and that they possess larger internal cavities with more and larger crystals in them. It may well be that these nodules are continually undergoing modification by the transfer of mineral matter from the inside to the outside as the result of the surface evaporation of capillary water absorbed during wet weather. J. D. Lauder milk¹¹ has ascribed the formation

¹⁰ Cf. W. A. Richardson, “On the Origin of Septarian Structure,” *Min. Mag.*, Vol. LVI (1919), pp. 327-38.

¹¹ “On the Origin of Desert Varnish,” *Amer. Jour. Sci.*, Vol. XXI (1931), pp. 51-66.

of "desert varnish" on boulders to this process; and there seems to be no reason why it should not be equally effective, if not more so, in producing modifications in the structure of relatively soluble concretions and nodules.

The mudstone at Mabelle Draw is singularly devoid of fossils. The only recognizable organic remains which it is known to have yielded so far are a few bones of a small unidentified reptile or amphibian, incased in purple barite. No traces of any plants or invertebrates (including microfossils) have yet been found.

LIMESTONE

Unfortunately, as is the case with most of the limestones in the Clear Fork and Wichita groups, the two layers that figure in the section at Mabelle Draw pinch out and disappear before they reach the marine "Albany" sequence farther south. This circumstance increases, to some extent, the difficulty of correlation; but the remarkable thing, after all, about these limestones, is not that they fail to connect with the "Albany" but that they do persist, in spite of their thinness, over such wide areas. The stratigraphic irregularity and discontinuity of the intervening "redbeds" in many sections is notorious; but it must be conceded that the environment in which the limestones were deposited was characterized, in general, and for the time being at least, by a high degree of geographical uniformity.

The two layers are very similar in their general appearance. They weather into massive, rounded blocks which mantle the slopes below the outcrops for considerable distances. In structure, too, they are almost identical. The upper surface of both layers is generally smooth and featureless, but locally it may exhibit well-defined mud cracks. The lower

surface is commonly covered with coarse swellings, which are reminiscent of the swellings observed on the surfaces of seam-type concretions in the mudstone. The rock is fine-grained, soft, porous, and of impure composition. It contains numerous irregular little seams of greenish clay and yields a generous clay residue on digestion with acid. As in the mudstone, all trace of depositional lamination is notably lacking. Invertebrate fossils—or, rather, their empty molds—occur locally in profusion, and they are invariably jumbled together like the pebbles in an edgewise conglomerate, instead of being arranged in regular layers. The larger molds are often found to contain large, yellowish crystals of barite. Cracks and other cavities are commonly discolored by dendrites and limonite stains.

The following species of invertebrates have been identified from the limestone layers at Mabelle Draw:

Anthozoa

Syringopora multattenuata

Pelecypoda

Myalina permiana

Pleurophorus subcuneatus

Gastropoda

Murchisonia terebra

Strophostylus remex

Cephalopoda

Metacoceras dubium

Orthoceras rushense

Phacoceras dumblei

Ostracoda

Knoxina indistincta

Paraparchites oviformis

Examples of these species are figured in Plate I of the writer's dissertation, and systematic descriptions are given in an appendix.

The occurrence of these fossils is taken as proof that, during the intervals of limestone deposition, the site of Mabelle

Draw was covered—intermittently, at least—by marine waters. These waters belonged, presumably, to the Leonard Sea, which at this time occupied a large area in western Texas and eastern New Mexico.¹²

IMBRICATED DEPOSIT

As explained previously, the imbricated deposit is a local one which overlies the fossiliferous deposit and extends for a considerable distance beyond its margins. It is a noteworthy fact that the contact of the imbricated deposit with the underlying fossiliferous deposit is distinctly disconformable. A considerable portion of the upper part of the fossiliferous deposit was apparently eroded away before the bulk of the imbricated material was laid down. The imbricated deposit also contains disconformities within itself; but its contacts with the mudstone, in general, are conformable.

Owing to the superior resistance of its partially indurated sandstone layers, the imbricated deposit has remained at the surface over wide areas where the mudstone has been stripped away, and its structural features are therefore well displayed. In the thicker sections around the margins of the fossiliferous deposit, where the imbricate structure is best developed, the individual layers are generally inclined northward at an angle of about 5°. There is much local variation, however, for one set of imbricated layers is often found to truncate another set along the strike, and reversals of dip are not uncommon. Where the deposit is thinner, overlying the fossiliferous deposit, there is less regularity of structure; and individual layers may be lenticular or may curve upward and truncate one

another in a manner suggestive of eolian cross-bedding. It is not unusual, at some places along the contact, to find large and small lenses of "imbricated" material more or less buried in the fossiliferous deposit.

An outstanding minor feature of the structure of the imbricated deposit is the remarkable prevalence of ripple laminae. At least 60 per cent of all the material in the imbricated deposit seems to have been laid down in ripple structures. Each successive lamina is generally truncated by the one next above; and it is rather difficult, for this reason, to secure any slabs which show the ripples in their original form, but their cross-sectional profiles indicate that both current and oscillation ripples are present.

It is perhaps worth noting that the asymmetry of the current ripples indicates a prevalently southward direction of current movement. This would mean that the northward-dipping imbrication of the deposit as a whole must have been brought about by "hindset" bedding on the currentward, or "stoss," side of the growing deposit. True foreset cross-bedding does occasionally occur within the imbricated layers and invariably runs counter to the direction of imbrication. The writer sees no particular significance in this somewhat unusual arrangement and attributes it merely to local vagaries in current and bottom conditions.

The superior sorting of the imbricated deposit, compared with the fossiliferous deposit, has already been noted. Layers of coarse and fine material may be intricately interlaminated, but they are almost invariably distinct—whereas, in the fossiliferous deposit, clay, silt, and sand are thoroughly intermingled.

Texture histograms of material from the sandier layers of the imbricated deposit indicate a high concentration of

¹² For correlation, and paleogeographic map, see Charles Schuchert and C. O. Dunbar, *Historical Geology*, Part II of *A Textbook of Geology* (4th ed.; New York: John Wiley & Sons, 1941), pp. 274, 283.

particles in the $\frac{1}{8}$ – $\frac{1}{16}$ and $\frac{1}{16}$ – $\frac{1}{32}$ mm. brackets and an almost total absence of material coarser than $\frac{1}{8}$ mm. There is commonly a secondary mode in the clay range, which appears to be due to sampling across laminae. Nearly all the coarser particles are well-rounded quartz grains. The significance of these features may best be appreciated by comparison with the textural characteristics of the fossiliferous deposit, which are discussed on a subsequent page.

The imbricated deposit, by comparison with the fossiliferous deposit, is relatively barren of the remains of organisms, though it does, here and there, yield a worn bit of bone or the rough impression of a twig, stem, or leaf.

The most interesting fossils yet found in this deposit are some unusually large footprints, which are preserved as casts on the undersides of slabs of sandstone (Fig. 8 of the writer's dissertation). These footprints are believed to be larger than any hitherto described from the Texas Permian¹³ and were presumably made by one of the larger species of tetrapods represented by the bones in the fossiliferous deposit. Unfortunately, no "trails" have yet been found—only individual tracks. The footprint casts are accompanied by casts of stem impressions, rill marks, and mud cracks, which are interpreted as indications of recurrent withdrawals of the water in which the imbricated deposit was being laid down.

DESCRIPTION OF FOSSILIFEROUS DEPOSIT

The fossiliferous deposit, as previously noted, is of strictly local extent. Its

¹³ Cf. R. L. Moodie, "Vertebrate Footprints from the Texas Redbeds," *Amer. Jour. Sci.*, 5th ser., Vol. XVII (1929), pp. 352–68; also *idem*, "Vertebrate Footprints from the Texas Redbeds, II," *Jour. Geol.*, Vol. XXXVIII (1930), pp. 548–65.

rather complicated contact with the overlying imbricated deposit has already been discussed. The lower contact, in contrast to the upper one, is simple and easily recognizable, though "camouflaged" to a certain extent by the bleached condition of the adjacent mudstone. The contact is actually exposed for only very limited distances along the creek bottom (Fig. 2), but enough is visible to reveal its character: a distinct unconformity cutting a broad, shallow channel in the underlying mudstone.

The internal structure of the fossiliferous deposit, though obliterated on weathered slopes, may be observed in detail in the numerous exposures which are kept fresh by the undercutting meanders of Mitchell Creek. In general, it may be said that the structure is much less regular and less clearly defined than that of the imbricated deposit. In some exposures it is of the type which has been described as "cut-and-fill" structure; but elsewhere there is only a vague sort of horizontal "bedding," with much interfingering and intergrading of the various ill-defined layers.

The writer was unable to find in the fossiliferous deposit any foreset crossbeds or other structures indicative of the direction of current flow. Even the ripple marks—so conspicuous in the overlying imbricated deposit—seem here to be altogether wanting.

As might be expected, from the indistinctness of its bedding, the fossiliferous deposit yields texture histograms which indicate a very low order of sorting. In other respects these histograms bear a rather striking resemblance to those derived from the imbricated deposit. Like the latter, they exhibit a notable scarcity of particles coarser than $\frac{1}{8}$ mm. and a decided concentration of particles in the $\frac{1}{8}$ – $\frac{1}{16}$ and $\frac{1}{16}$ – $\frac{1}{32}$ mm.



FIG. 2.—Geologic map of Mabelle Draw, showing outcrops of fossiliferous deposit (stippled), imbricated deposit (black), and limestone layers (thin black lines around rim of draw). Remainder of exposed material is mudstone.

brackets. It is noteworthy, also, that the fine sand particles from these two deposits are almost indistinguishable as regards composition, surface texture, sphericity, and roundness.

The general restriction in particle size to diameters of less than $\frac{1}{8}$ mm. is somewhat anomalous, in view of the fact that the fossiliferous deposit contains several isolated lenses of conglomerate with pebbles ranging up to the size of hens' eggs. The "pebbles," to be sure, are not of the ordinary variety, and it was thought at first that they might be merely hardened mudballs. They consist, however, of dense, gray, argillaceous calcite, without a trace of mudball structure, and give every evidence of having originally been concretions, like those which now occur in such abundance in the surrounding mudstone. Many of them even contain "shrinkage cracks," which are like those in the seam-type concretions except that they are commonly lined with pyrite, galena, and other sulphides, instead of with barite. This difference, however, may merely indicate that—while growth of the concretions began during, or soon after, deposition—the mineralization of their internal cavities did not take place until after some portions of the mudstone had been re-worked into new deposits.

At all events, the presence of these pebbles would seem to prove that the otherwise fine texture of the fossiliferous deposit is more the result of fineness of the available sediment than of any lack of transporting power in the currents which were there to carry it.

The pebble bars, while deposition was going on, seem to have functioned as traps for miscellaneous organic fragments. The nooks and crannies between the pebbles are full of odds and ends of bone fragments, teeth, coprolites, bits of

carbonized wood, and shells of invertebrates. Unfortunately, most of this material, though well preserved, is rather hard to get at, since the lime-rich pebble layers are now firmly cemented together into solid masses of conglomerate.

Vertebrate remains are abundant in various portions of the fossiliferous deposit. All the material is disarticulated, and much of it is broken and waterworn. Many specimens are incrustated with gypsum. The color of the bone is usually black or bluish black.

The genera which have been identified from this material are as follows:¹⁴

Reptilia

Diadectes

Dimetrodon

Ophiacodon

Amphibia

Cricotus

Eryops

Trimerorhachis

Pisces

Acrolepis

Pleuracanthus

It will be noted that all these genera, with the possible exception of *Acrolepis*, are regarded as fresh-water, or terrestrial, in habit. Their presence in the fossiliferous deposit clearly indicates that this mass of sediment was brought in—if not actually laid down—by fluvial agencies.

There are also many plant remains in the fossiliferous deposit, ranging from the most delicate leaf structures to massive stumps and logs.

The leaves—along with twigs, stems, seeds, cones, etc.—are locally very abundant and appear to have been drifted together in patches of slack water before

¹⁴ Examples of the material referred to these genera are figured in Plate II of the writer's dissertation, and systematic descriptions are given in an appendix.

burial. Much of the material was apparently rotten and more or less macerated; but a portion of it which was not too badly battered to begin with has come down to the present in an excellent state of preservation. It is all carbonized, of course, and very much compressed; but the writer has found some leaf structures so little altered that they could be lifted intact from the layers of sediment in which they were preserved. Unfortunately, the best specimens commonly occur in seams of very fine, pure clay which checks so badly on drying that it is extremely difficult to handle.

Quite a number of the leaf specimens have been identified as belonging to recognized species of land plants, which are as follows:¹⁵

Pteridospermophyta

Brongniartites? yakiensis
Gigantopteris americana
Odontopteris newberryi
Pecopteris tenuinervis
Taeniopteris coriacea
T. newberriana

Coniferophyta

Cordaites principalis
Paleotaxites praecursor
Walchia piniformis

The logs and stumps are scattered in a haphazard manner which seems to indicate that they too were drifted in and did not grow in the places where they were buried. Some may have been transported for considerable distances, for they were apparently stripped of all leaves and branches and most of their bark before finally coming to rest. The larger logs may be 8 or 10 feet long and seem to have come from straight trunks averaging about 8 inches in diameter. All are now more or less oval in cross section,

owing to compression by the weight of overlying sediments.

Unfortunately, none of the specimens studied by the writer have retained enough of their original stelar morphology to permit accurate identification. In many, the original cell structure has been almost completely obliterated by the growth of calcite spherulites.

A number of short sections of petrified pith have been found which are covered externally with slender rhomboidal bosses in crossed spiral rows. A. C. Seward¹⁶ mentions various pith casts from the Permian of Europe which exhibit a surface pattern of this type and refers them to the form-genus *Schizodendron*. This name was originated by Edouard d' Eichwald,¹⁷ in 1860, who thought that the casts in his possession represented complete trunks and interpreted the rhomboidal areas as leaf scars. Henri Potonié,¹⁸ in 1888, showed that these areas correspond to the inner ends of medullary rays in the surrounding xylem and that the groove at the bottom of each one of them was occupied by an outgoing leaf trace.

Schizodendron piths have been attributed by various authors¹⁹ to *Walchia*; but there is, as yet, no definite proof of this connection, and they may belong to any of several genera of Permian coniferales which had spirally arranged leaves.

In sum, it may be said that the evidence afforded by the plants is such as to indicate that the sediment in the fos-

¹⁶ *Fossil Plants* (Cambridge: University Press, 1919), Vol. IV, pp. 282-86.

¹⁷ *Lethaea Rossica* (Stuttgart: E. Schweizerbart, 1853-68), Vol. I, pp. 265-68, Pl. 18, Fig. 10, and Pl. 20, Fig. 11.

¹⁸ "Die fossile Pflanzen-Gattung Tylocladon," *Jahrb. kgl. preuss. geol. Landesanst.* (1888), p. 311.

¹⁹ For discussion and bibliography, see Seward, *op. cit.*, pp. 285-86.

¹⁵ Examples of these species are figured in Plate II of the writer's dissertation, and systematic descriptions are given in an appendix.

siliferous deposit came from a river large enough, and persistent enough, to have supported a considerable fringe of perennial vegetation in a region whose general aridity is attested elsewhere by the occurrence of extensive salt deposits.²⁰ It may well be that the annulations in the xylem of the fossil logs are the result of pronounced seasonal fluctuations in water supply—such as are characteristic of large rivers flowing through arid regions today.

In view of all the foregoing evidence in support of a fresh-water origin for the sediments of the fossiliferous deposit, it is rather surprising, at first thought, that the deposit should also contain invertebrate remains of undoubted marine affinities. The most interesting occurrence is that of *Myalina permiana*, a common species of the overlying limestones. Shells of *Myalina* are so abundant in certain portions of the conglomerate masses as to form solid seams 2 or 3 inches thick. The shells are macerated and obviously did not grow in the places where they were buried. There is a possibility that the species may have migrated, like oysters, into the lower reaches of rivers and that the shells were washed down again by the same fluvial currents which transported the plant and vertebrate remains; but there is at least an equal possibility that they were brought in by marine currents and are indicative of tidewater conditions at the very mouth of the river.

In addition to *Myalina*, the conglomerates also contain a great many shells of a species of *Spirorbis* (which likewise

occurs in the limestones). Occasional specimens of these and other species are found in the beds of silt and clay.

INTERPRETATIONS AND CONCLUSIONS

In recapitulation: The limestone layers, with their salt-water fossils, can scarcely be of other than marine origin. On the other hand, the fact that the tops of the layers are mud cracked indicates that deposition must have taken place in very shallow water—probably between high- and low-tide levels. The presence of so much argillaceous material within the limestone layers, as well as above and below them, suggests that the site of deposition was not far from the mouth of some large river. The absence of internal laminations and the edgewise arrangement of the fossils are interpreted to mean that the limestone was originally laid down as a soft lime ooze. The "swollen" condition of the bottoms of the layers is believed to be the result of progressive downward solidification after burial. The continuity and uniformity of the layers, over wide areas, imply commensurate continuity and uniformity in the site and circumstances of deposition.

Most of the foregoing conclusions are based on sedimentological evidence. There are, undoubtedly, certain special attributes of the invertebrate fauna—both individually and collectively—reflecting the influence of certain equally special conditions of the environment which are not sedimentologically recorded. But, in the opinion of the writer, the significance of the individual peculiarities of fossil faunas like this one is not, as yet, sufficiently well understood to permit the drawing of many conclusions concerning the ecological factors responsible for them. It is not even certain, in the first place, that the assemblage which occurs at Mabelle Draw is a true ecological unit.

²⁰ For the occurrence of salt in beds equivalent to the Lueders formation, see George H. Norton, "Permian Redbeds of Kansas," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XXIII (1939), pp. 1755-58. For correlation, see C. L. Mohr, "Subsurface Cross Section of Permian from Texas to Nebraska," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XXIII (1939), p. 1708.

The nautiloids, for instance, may have been floated in, as empty shells, from regions far removed from their place of burial.

Inasmuch as it has yielded no marine fossils, the mudstone might conceivably be nonmarine. However, its remarkable uniformity over wide areas—coupled with the fact that it is interbedded, in its typical form, with the layers of limestone—is strongly suggestive of a marine origin. In fact, the mudstone may well represent the normal type of marine deposition in this area—the limestone being merely a variation due to some temporary change in the aqueous environment which led to the precipitation of calcium carbonate along with the usual mud.

On the other hand, if the mudstone is marine, its red color and peculiar structural characteristics are not quite so easy to explain. Shallow-water marine muds are generally full of organic matter; and no deposit which contains much organic matter is likely to acquire, or to retain, the characteristics of "redbeds." There are two possible solutions to this enigma: either the mudstone, for some reason, contained very little organic matter to begin with; or else it lost most of what it once did contain, by aeration before burial. In the writer's opinion, the second alternative is the correct one. It is true that there are very few fossils in the mudstone, and this circumstance might seem to favor the other possibility. But the limestone is full of fossils and is thought to have been deposited under much the same circumstances as the mudstone; so it seems more plausible to assume that the organic material was originally present but that it was "baked out," or destroyed by bacteria, when the mud flats were exposed to the heat of the sun at low tide.

The removal of shells and other hard parts cannot, of course, be ascribed to aeration and must be attributed to subsequent solution by ground water. It will be recalled, in this connection, that the shells originally in the limestone are represented only by casts. In view of this fact, it does not seem unlikely that any shells which were originally present in the relatively unindurated mudstone might have disappeared without leaving a trace.

The hypothesis of a littoral origin for the mudstone has so far been based primarily on indirect evidence from the limestone. Additional evidence in its support is found in the imbricated deposit, where mudcracks, footprints, rill-marks, and scattered lenses of material cross-bedded in the eolian manner, occur among layers with abundant ripple marks and other evidences of the aqueous environment. There is no direct proof, in the case of the imbricated deposit, that these waters were marine; but the structural features of the deposit are precisely those which are produced by the transporting agencies which presumably operated, though with different materials, during the deposition of the limestone and the mudstone. These agencies would have been waves and currents at high tide and the wind at low tide. If the fossiliferous deposit was here first, as it obviously was, to provide the material to be re-worked over the surface of the mudflats, there is nothing about the imbricated deposit which does not fit perfectly into the concept of a littoral environment. The presence of isolated lenses of imbricated material below the top of the fossiliferous deposit would merely indicate that the process of re-working was already under way before deposition of the fossiliferous deposit had been completed.

The absence of invertebrate remains is here attributed, as in the case of the mudstone, to the solutional effects of groundwater. To explain the absence of molds in the indurated sandstone layers, it is only necessary to assume that solution took place before induration.

The fossiliferous deposit, with its abundant remains of terrestrial organisms, must obviously have been derived from fluvial sources. It might possibly have been laid down by littoral currents off the mouth of some river, but the structure and texture of the deposit are such as to indicate that the river was still in control when final deposition took place. The "cut-and-fill" bedding and imperfect sorting are almost certainly the work of shifting and fluctuating stream currents, rather than the more uniform currents of the sea.

If actually a stream did cut across the tidal mud flats in this locality and gouged out a shallow channel to be filled subsequently with the sediments of the fossiliferous deposit, as the evidence seems to indicate, this stream can have looked like an ordinary stream only at low tide. At high tide it must have been merely an offshore fluvial current, precariously held to its usual course by the confining influence of its own submerged levees. As deposition progressed and the original channel gradually silted up, the influence of the levees must have lasted long enough to have permitted aggrading of the stream bottom to a level higher than that of the surrounding mudflats. Thus, when the channel was finally abandoned, a long, elevated mass of river material would have been left behind, to be reworked slowly by the waves and currents of the littoral zone.

The sudden appearance of a sizable stream and its subsequent disappearance may best be attributed to the temporary opening-up of a new distributary at the mouth of some large river. Such occurrences are common in present rivers during times of flood, and, indeed, the "fresh" appearance of so many of the plant remains may well indicate that they were torn off by a storm rather than dropped off in the normal course of withering and decay.

In summation: If the writer has correctly interpreted his evidence, the fossiliferous deposit at Mabelle Draw is to be regarded as the product of a brief episode of fluvial activity interrupting the normal progress of marine deposition in an extended littoral environment. The available data do not permit a precise cartographic reconstruction of the scene in which this event took place, but it may safely be assumed that the general physiographic background was not greatly different from that along certain portions of the Gulf Coast of the United States today. The "gulf," in this case, was the Leonard Sea; and the adjacent coastal plain was the western margin of an interior lowland which was bordered, on the south and east, by mountains much younger and far more rugged than the present Ouachitas and Appalachians. The climate was more arid, and the vegetation and animal life more primitive; but, in spite of these differences and the changes wrought by time, the sediments of Mabelle Draw seem to be fundamentally similar to those forming at the mouths of numerous rivers which today are weaving the record of their existence into the voluminous mud flats of the Gulf.

